PH4041 – Atomic, Nuclear, and Particle Physics

Credits: 15.0  Semester: 1
Number of Lectures: ~27  Lecturer: Dr Donatella Cassettari and Dr Antje Kohnle
Academic Year: 2016-17

Overview
The aim of this module is to describe in terms of appropriate models, the structure and properties of the atom, including its nucleus, the classification of fundamental particles and the means by which they interact. The syllabus includes: electron cloud model of an atom, electron spin and magnetic moment, spin-orbit interactions, revision of single-electron atom and brief qualitative extension to multi-electron atoms, selection rules and line intensities for electric-dipole transitions; nuclear sizes, binding energy, properties of the strong nuclear force; radioactivity, the semi-empirical mass formula; nuclear stability, the shell model, magic numbers; energetics of beta-decay, alpha-decay and spontaneous fission; nuclear reactions, resonances; fission; electroweak and colour interactions, classification of particles as intermediate bosons, leptons or hadrons. Standard model of leptons and quarks.

Aims & Objectives
To present an introductory account of atomic and nuclear physics and elementary particle physics, including
- to enhance our understanding of the internal structure of atoms and understanding of atomic interactions with magnetic and electric fields.
- scattering experiments, observational aspects of nuclei, including their binding energy, size, spin and parity - nuclear models: liquid drop and shell models
- the semi-empirical mass formula and deductions from it concerning nuclear stability
- the classification of fundamental particles and their interactions according to the Standard Model - quark structure of mesons and baryons.
- properties of the strong and weak interactions

Learning Outcomes
By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures and be able to:
- Explain the electronic structure of alkali atoms.
- Building on time-dependent perturbation theory seen in PH3062 (Quantum Mechanics 2), explain aspects of atom-light interactions such as selection rules in optical transitions.
- Explain the effect of magnetic interactions on electronic energy levels: these include the fine structure arising from spin-orbit interaction, and the Zeeman effect arising from the interaction with an external magnetic field.
- Explain methods used to extract information about nuclei and particles through scattering experiments, and be able to derive quantitative information through calculations for simple cases.
- Apply concepts from special relativity, quantum mechanics and atomic physics to describe subatomic systems.
- Explain the assumptions, limitations and ranges of applicability of the liquid drop model and shell models of the nucleus.
- Use the liquid drop model and the law of radioactive decay to describe alpha-decay, beta-decay, fission and fusion, predict decay reactions and calculate the energy release in nuclear decays.
- Determine nuclear properties such as binding energy, spin and parity in the framework of the liquid drop model and the shell model of the nucleus.
- Articulate a considered and differentiated view on nuclear power generation founded on the physical principles of induced fission.
- Apply principles of relativistic kinematics to calculate kinematic quantities in reactions and decays.
- Describe interactions arising from fundamental forces in terms of Feynman diagrams and apply conservation laws to predict the type of interaction.
- Explain the experimental evidence for quarks, gluons, quark confinement, asymptotic freedom, sea quarks, the running coupling constant and colour charge.
- State the key ideas of the Standard Model of particle physics, and name some currently unsolved problems in particle physics.
- Name important current particle accelerators and state their centre-of-mass energies.
- Apply the concepts of quark generation mixing, helicity and parity violation to weak interactions.

Synopsis

From the start of semester to approximately week 4:
Atomic structure of hydrogen and of the alkali metals.
Atomic spectra and selection rules for optical dipole transition.
Introduction to spin-orbit coupling, fine structure of spectral lines.
Ordinary Zeeman effect.

From approximately week 4 to week 11:
Binding energy of nuclei, liquid drop model of the nucleus - Stability of nuclei, alpha-decay, beta-decay, fission, fusion - nuclear shell model
Scattering, relativistic kinematics, cross section, luminosity, mean free path, Fermi's second golden rule, resonances
The four fundamental interactions and Feynman diagrams
The standard model of particle physics: Quarks, gluons and hadrons
The standard model of particle physics: Phenomenology of the weak interaction

Pre-requisites
PH2011 (Physics 2A), in particular special relativity
PH2012 (Physics 2B)
MT2001 or (MT2501 and MT2503)
PH3081 or PH3082 (Maths for Physicists / Phys/Chem) or (MT2003 or [MT2506 and MT2507])
PH3061 (Quantum Mechanics 1) and PH3062 (Quantum Mechanics 2)

Anti-requisites
PH4022, PH4037, PH4040

Assessment
2 hour examination = 90%, Coursework (online quizzes and clicker participation) = 10%

Additional information on continuous assessment etc
Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.
5% of the module mark is based on five online quizzes with submissions in weeks 4, 7, 8, 10 and 11.
5% of the module mark comes from active participation with the question and answer system in lectures.

Accreditation Matters
This module contains material that is or may be part of the IOP “Core of Physics”. This includes
Energy momentum relationship
Nuclear masses and binding energies
Radioactive decay, fission and fusion
Pauli exclusion principle, fermions, bosons, and elementary particles
Fundamental forces and the Standard Model

Recommended Books
Please view University online record:
http://resourcelists.st-andrews.ac.uk/modules/ph4041.html

General Information
Please also read the general information in the School's honours handbook.